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Open-Cast Mining Reclamation
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In addition to science, imagination is needed to see the potential of the land and to relate it to the need of the local region.

Bradshaw, 1988

Key Points to Retain

Application of an inadequate conceptual framework is often behind the failure of mining reclamation projects, including insufficient understanding of reference ecosystems, short-term planning, and insufficient consideration of contingencies.

Cooperation between mining companies and environmental institutions is necessary to integrate reclaimed areas into conservation programmes at a regional scale.

Good erosion models for reclaimed areas as tools for land-form design have been developed.

One major area in need of improvement is the application of laws that require rehabilitation of mined sites.

1. Background and Explanation of the Issue

Human activities involving major soil removal, such as open-cast mining, urban development, civil works, and so on, are the first source of sediment reaching the oceans via rivers. At a local scale, mining impacts on biodiversity, water quality, and land use are frequently very high. Mining is one of the anthropic activities causing some of the most dramatic disturbances on nature. In fact, there is a positive feedback interaction between nonenergetic and energetic mineral extraction, which also contributes to greenhouse gas emissions. Technology for mining reclamation has been widely developed in the last two decades for most regions of the world. However, in practice, most of the “reclaimed lands” have achieved poor results.455

Application of an inadequate conceptual framework is often behind the failure of mining reclamation projects. There are two types of driving forces in mining reclamation: determinism and contingency.456 Usually only deterministic processes are considered. In addition, reclaimed areas must be recognised as open ecosystems interacting with their surrounding environment. A conceptual model including its practical consequences on mining reclamation planning is shown in Figure 53.1. This model assumes that change more than equilibrium is the essence of nature, following the new paradigm in ecology.457

Reclamation success depends on several contingent or circumstantial events, which are often unpredictable: (1) initial conditions

(natural climate and topography, type and abundance of topsoil); (2) natural perturbations (droughts, extreme rainfall events, frost periods, pests); (3) influence of the surrounding ecosystems and people (runoff and sediment flows, sources of propagules, herbivorism, grazing, hunting, land uses); and (4) human contingencies (modification/intermittence of mining operations; mistakes in the performance of reclamation works; changes in legal rules, etc.).

Deterministic processes involved in mining reclamation have been well studied and a wide set of reclamation techniques and tools have been developed. Most typical of them in mining reclamation are abiotic limiting factors and nutrient cycling. Bradshaw\textsuperscript{458} identified the main physical and chemical problems that can be found in mine soils and their short and long-term treatments, which are shown in Table 53.1.

Following the proposed conceptual framework, the Reclamation Planning box in Figure 53.1 shows the main issues that should be considered, from the practical perspective, in order

\textsuperscript{458} Bradshaw, 1988.
to improve the performance of open-cast mining reclamation.\textsuperscript{459} In addition:

1. Both mining and reclamation activities must be carried out simultaneously in an integrated way in order to optimise the opportunities offered by mining operations. This makes reclamation works cheaper, quicker, and more successful.

2. Reclamation projects must be designed and developed by companies and social actors together. It is critical to get an agreement about the final objectives for the reclaimed areas as well as their use and maintenance.

3. Although general protocols for reclamation are available, it is always necessary to carry out specific research in order to adapt or develop them to the local conditions and to obtain in depth knowledge about the reference ecosystem. Cooperation between companies and conservation organisms and nongovernmental organisations (NGOs) is valuable for this phase.

4. A plan of monitoring and survey is essential for checking, improving, or redirecting the applied practices.

\begin{table}[h]
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\caption{Specific problems of mine soils and their treatments (Bradshaw, 1988).}
\begin{tabular}{|l|l|l|l|}
\hline
\textbf{Category} & \textbf{Problems} & \textbf{Immediate treatment} & \textbf{Long-term treatment} \\
\hline
Physical Structure & Too compact & Rip or scarify & Vegetation \\
& Too open & Compact or recover with fine material & Vegetation \\
Stability & Unstable & Stabiliser/mulch & Vegetation \\
Moisture & Too wet & Drain & Drain \\
& Too dry & Organic mulch & Vegetation \\
Nutrition Macronutrients & Nitrogen & Fertiliser & Legume \\
& Others & Fertiliser + lime & Fertiliser + lime \\
Toxicity pH & Too high & Organic matter or pyritic waste & Weathering \\
& Too low & Lime & Lime \\
Heavy metals & Too high & Organic mulch or tolerant cultivar & Inert covering or tolerant cultivar \\
Salinity & Too high & Weathering or irrigate & Tolerant species or cultivar \\
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2. Examples

2.1. Fire Management in Jarrah Forest Restoration on Bauxite Mines in Western Australia\textsuperscript{460}

Alcoa World Alumina Australia commenced mining bauxite in the Jarrah forest of western Australia in 1963. Since then, 10,600 hectares have been rehabilitated. The climate is typically Mediterranean with winter rainfall and summer drought. Early restoration efforts were based on imported species of pine and eucalypt from Eastern Australia. This exotic vegetation is very resilient to natural forms of disturbance, so plant richness remains low and ecological succession runs slowly. The current rehabilitation objective is to reestablish a functional Jarrah forest ecosystem that will fulfil the forest land uses (conservation, timber production, water catchment protection, and recreation). Rehabilitation began with the reshaping of the 2- to 5-m-high pit walls. Topsoil was re-spread. As topsoil returned, a few tree stumps, logs, and rocks were returned to the mined areas to provide habitat for fauna. The ground was ripped to a depth of 1.5 m. A seed mix of 70 to 100 local species was broadcast on the freshly cultivated ground. Other plant species were

\textsuperscript{459} Adapted from Australian Environmental Protection Agency, 1995.
\textsuperscript{460} Smith et al, 2004.
planted. A mixed fertiliser (nitrogen, phosphorus and potassium (NPK) and micronutrients) was applied at 500 kg per hectare by helicopter.

In 1997 Alcoa and the Department of Conservation and Land Management (CALM) developed completion criteria and standards. Specifically, the completion criteria require restored areas to be resilient to fire and capable of integration into CALM’s Jarrah forest fire management programme. Alcoa supported research to determine how the vegetation and associated faunal communities respond to fire, in order to define when and under what conditions fire should be reintroduced into rehabilitated areas.

2.2. Restoring Tropical Forests on Lands Mined for Bauxite—Examples from Brazilian Amazon

Since 1979, the Brazilian mining company Mineração Rio do Norte (MRN) has developed a reforestation programme aimed at restoring the evergreen equatorial moist forest destroyed at a rate of 100 hectares per year during bauxite ore extraction at Trombetas in western Pará State. The Trombetas bauxite mine is located in the Saracá-Taquera National Forest on an upland mesa at an elevation of 180 m. Restorationists working in most tropical settings are usually hampered by lack of basic information on the wide variety of native tree species that characterise the pre-disturbance forests, as well as insufficient understanding of the ecology of disturbance and natural recovery to design effective restoration programmes. A notable exception is MRN, which has used a systematic nursery and field research strategy to develop a reforestation programme based on mixed plantings of more than 70 native old-growth forest tree species.

Two main research programmes were carried out in the last 11 years, and a number of reforestation methods as well as site preparation and topsoil replacement protocols were tested. Native forest species’ propagation and performance assessment programmes involved evaluations of fruiting phenology, seed viability, seed germination treatments, propagation methods (direct seeding, use of stumped saplings, wildings, and nursery-grown seedlings), and early survival and growth during the first 2 years after outplanting. A total of 160 species were evaluated. The standard reclamation and site preparation sequence was followed, which includes levelling of the clay overburden, replacement of approximately 15 cm of topsoil and woody debris (removed from the site prior to mining and stockpiled for up to 6 months prior to application), deep-ripping of lines to a depth of 90 cm (1 m between lines), and planting along alternate rip lines at 2- by 2-m spacing (2500 trees per hectare) using seeds, stumped saplings, or potted seedlings, depending on species and treatment. The total cost came to approximately $2500 per hectare.

The following conclusions can be drawn: Careful site preparation practices, particularly judicious topsoil handling and reapplication prior to tree planting, are essential for the establishment of forest cover, elimination of competing grasses, and acceleration of natural forest succession. Floristic enrichment of the reforested areas is largely dependent on seed-dispersing wildlife, so restoration managers need to be cognizant of the critical role of wildlife, actively encourage wildlife conservation in the surrounding landscape, and design restoration treatments that will provide suitable habitats for a variety of target wildlife species.

2.3. Open-Cast Coal Mining Reclamation in Utrillas-Teruel (Spain) in a Semiarid (Mediterranean-Continental) Environment

Minas y Ferrocarril de Utrillas, SA (MFUSA) company commenced open-cast mining in the Utrillas coalfield in the early 1980s. The area is

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located in central-eastern Spain at 1100 m of altitude. A major limiting factor is water deficiency in soil, and therefore reduced water availability for plants. Mean annual rainfall is 466 mm, 28 percent falling in June and May and 20 percent in September. The water deficit is 292 mm from June to October. Restoration of the mines was orientated toward agricultural uses in agreement with social actors.

Improving soil moisture content was the key success factor in the Utrillas region. The MFUSA company developed a restoration protocol in which the three elements of the ecosystem, namely, landform, soil, and plants, were designed in an integrated fashion to optimise the supply of water and nutrients and to control the abiotic exploitation of erosion.

Land forms based on the platform-bank model with slopes of about 30 degrees had to be abandoned because rainfall infiltration is low in steep slopes, and runoff leads to high rill and sheet erosion. In turn, rill erosion increases water deficiency at the slope scale by reducing opportunities for runoff re-infiltration into the soil downslope. The best-identified topography was that based on the hydrological basin as unit for reclamation. This is composed of slopes with natural vegetation, flat areas for agricultural use, and a drainage network including watercourses, pools and sediment ponds. Topsoil was carefully selected for its physical properties (water-holding capacity).

Characteristics of constructed slopes were as follows: gradient between 18 degrees and 21 degrees; insulation from runoff from platforms, tracks, and upper berms; topsoil spreading (50 cm thick); tillage transverse to the slope; supply of organic fertiliser; sowing with herbaceous species at the end of winter; surface tillage to bury seeds. Three years later, in winter, woody species were planted.

This protocol has been successful to get grass back, which controlled soil erosion and started soil formation. However, ecological succession is proceeding slowly. In fact, introduced grass community have inhibited natural colonisation.

2.4. Problems in the Reclamation of Coal-Mine Disturbed Lands in South Wales Coalfield

Reclamation in South Wales started in Pwll Du mine in the 1940s. Three surface mines were reclaimed during the 20th century.

More recent land reclamation practice often involves applied topsoil (100 to 150 cm) and the establishment of seeded grass covers to allow sheep to graze. Reclaimed areas are managed by Commoners Associations.

However, large tracts of land, officially listed as “reclaimed” from former mineral operations, are in very poor condition. On-site problems include gullying, poor vegetation cover, erosion, and poor soil structure. Off-site they cause problems due to accelerated runoff and, more occasionally, chemical and sediment pollution. Some of these problems are due to poor engineering and poor land husbandry, but they are magnified by natural processes. Some mine spoils/soils include a high proportion of friable shales. These break down rapidly, when exposed to disturbance/weathering, releasing clays, which clog up soil pores and impede the infiltration of water. This causes a progressive deterioration of the land with symptoms that may include water logging, replacement of grass by moss/lichen/bare ground, dieback of soil microbiota, increases in soil bulk density, and decreases in soil aggregate stability.

Remedies that are being applied by the Oxford Brookes University group include developing a large/active soil microbiota capable of transforming clays in water-stable soil aggregates. This is done by introducing deep-rooting tree species because they are vigorous and reliable soil formers and because, with a little help, they can support large and active populations of microorganisms.

3. Outline of Tools

A wide set of tools can be found in the references below. The following tools are more specific to mining reclamation:

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463 Nicolau, 2002.

• The first measure for protecting the most valuable ecological areas from mining impacts should be the use of geographical information systems (GIS) plus environmental planning methodologies at the regional scale.

• In relation to topography design, Evans affirms that “to successfully incorporate the design of relief forms, the stability of the final forms must be predicted, which implies the use of hydrological and erosion models.” In recent years, some erosion models for reclaimed areas have been developed, which are now being used in relief design. We suggest using the RUSLE (Revised Universal Soil Loss Equation) 1.06 (for mined lands, construction sites, and reclaimed lands), which is a model that estimates the annual surface erosion by water and can be used for slope design. This model is available free on the Web site http://sedlab.olemiss/rusle.

• As off-site impacts on aquatic ecosystems are among the heaviest disturbances produced by open-cast mining, an erosion and runoff control plan is essential. Several software packages are available on the market. We recommend evaluating the effectiveness of erosion and sediment control plans. This can be acquired through the International Erosion Control Association at http://www.ieca.org.

• Topsoil handling is a key but easy issue when it is planned. A critical point is storage. It should be stored for a short period of time in small stockpiles. A second point is the spreading of topsoil on the reconstructed topography. To avoid soil compaction, such an operation must be carried out with topsoil that is neither too dry nor too wet.

• Soil amendment is a quite general matter in land reclamation. Table 53.1 shows a number of remediation procedures proposed by Bradshaw.

• A very useful “tool” from the practical point of view is to count on an environmental expert working in the field as mining and reclamation projects are going on. This person—in addition to being responsible for the fulfilment of the reclamation project—should foresee the contingencies and should profit from the opportunities offered by the physical environment, mining operations, local administration, and social actors.

4. Future Needs

Performance of surface mining reclamation shows high heterogeneity depending on the countries, the environments, and the companies; consequently, the needs are very different. In developed countries the main task is to reclaim again thousands of “reclaimed” hectares, which do not fulfil minimum requirements.

From the technical point of view the weakest points are land-form design and ecosystem dynamics knowledge. Erosion and hydrological models should be incorporated into reclamation planning. Also the reference ecosystem has to be used for reclaimed ecosystem design and to identify a number of successional trajectories, stable states, and thresholds of irreversibility.

In developing countries, efforts in research must be intensified as has been seen in the example of the Brazilian bauxite mine. Reclamation laws must be enhanced or enacted in some cases, but most importantly, laws must be observed and enforced. However, often in practice, this may seem utopian. In many cases mineral deposit discovery and exploitation means deep environmental impacts, social and political conflicts, corruption, and even armed violence. The imbalance is so high that often neither society nor the politicians are sufficiently prepared to have a positive relationship with the transnational mining corporations. Given such conditions, an international mining code of good practice would be useful.

We think that NGOs can be very helpful in: (1) promoting experimental research, (2) training local restorationists, (3) favouring local communities’ participation, and (4) advising governments of developing countries.

466 Toy and Foster, 1998.
468 Bradshaw, 1988.
References


Additional Reading


Section XIV
Plantations in the Landscape